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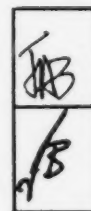
EXECUTIVE SUMMARY

ULTRASONIC INSPECTION OF TRAC BLISTERED TUBE #2

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CIGAR-type ultrasonics was performed on a Zr-Nb pressure tube containing a number of cracked and uncracked blisters. The main differences between this and standard CIGAR procedures were the use of a USIP 11 flaw detector and much smaller raster steps in comparison with CIGAR's general helical scans. The laboratory inspection showed that the cracked blisters were readily detectable, as much as 28 dB above the nominal recording level. Since these Zr-Nb blisters were under 2 mm in diameter, detectability was primarily dictated by raster step size, not by signal-to-noise ratio. The small Zr-Nb blisters showed regular images, in contrast to the large Zr-II blisters, probably because the cracking was smaller than the ultrasonic probe beam diameter so the Zr-Nb blisters acted as point reflectors. Pitch-catch characterization appeared to be an unreliable technique for differentiating cracked from uncracked small blisters, especially using a USIP 11.



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To

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Manager
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A7E2

ULTRASONIC INSPECTION OF TRAC BLISTERED TUBE #2

The TRAC #2 Zr-Nb pressure tube containing cracked blisters was inspected using CIGAR-type ultrasonics. Using small raster steps, the cracked blisters were readily detectable, with signal amplitudes up to 28 dB above threshold. The differences between the regular Zr-Nb blister images and the irregular images from Pickering Zr-II blisters can be tentatively explained by the relative blister/probe beam sizes. Pitch-catch did not appear to be a reliable technique for differentiating cracked from un-cracked blisters.

1.0 INTRODUCTION

The failure of Pickering NGS Unit 2 pressure tube G16 on August 1, 1983, was caused by the growth and cracking of hydride blisters due to pressure tube-calandria tube contact. Subsequent destructive examination of P2G16 showed that cracks had linked from blister to blister to cause the actual failure/1/. Since information on the state of the remaining tubes was immediately required, a non-destructive inspection drive, nicknamed CIGARette, was rapidly conceived, designed and built/2/. This system used standard CIGAR heads, containing multiple focussed ultrasonic probes for flaw detection. The CIGARette system could readily detect the blisters in Pickering 1 and 2, provided the correct area was scanned/3/.

The original Pickering 2 pressure tubes were made of Zr-II, which had typically absorbed 200 ppm or more of hydrogen/deuterium at the time of failure. At this hydride level, blisters were around 6 mm in diameter, and were routinely detected using CIGARette's 2 mm raster step and grass-level scanning sensitivity/4/. However, subsequent work on the newer Zr-Nb pressure tube material has shown that current hydride levels are much lower, typically 20-30 ppm, with estimated end-of-life levels of 60 ppm. At these hydride levels, blisters typically of the order of 2 mm in diameter are formed.

The objective of this inspection was to answer the question "How detectable are these smaller Zr-Nb blisters using CIGAR-type ultrasonics?" The report describes the ultrasonic inspection of the TRAC program blistered tube #2, which was one of two tubes used for testing the SLAR fast-scan blister detection system/5/.

2.0 BLISTER PREPARATION

The blisters were grown as part of the TRAC program, and attempt to realistically simulate the actual conditions in reactor (with the exception of radiation). The tubes were grown in the SPEL Pressure Tube rig using the cold contact technique. Tube #2 was prehydrided to a nominal level of 40 ppm. and put in contact with the calandria tube. Hot pressurized water at 293 degrees C flowed down the inside of the tube, while the moderator water on the outside of the calandria tube was kept at 65 degrees C. The tube was inspected after 150 and 250 days, and removed after 250 days. Contact load was 65 kg, using a "long contact" area. 36 blisters were profiled, with maximum height 0.048 mm, and average diameter 1.65 mm/6/.

The "shot-gun" pattern of blisters (rather than the line typically observed in service) is shown in Figure 1. Tubes #2 and 11 were selected for SLAR ultrasonic inspection due to the size of blisters. After initial inspection, both tubes were subsequently bent using a modified SLAR bending tool to determine if this procedure further cracked blisters, and the tube re-inspected. The limited ultrasonic dynamic evidence suggested no change, within normal repeatability/5/.

Twenty blisters on tube #11 and ten on tube #2 were tentatively selected for metallurgical sectioning, with tube #11 to be cut first. Tube #2 was then passed to Research for further ultrasonic inspection, the subject of this report.

The ten blisters selected for metallography to establish SLAR Probability of Detection were the five that showed a detectable ultrasonic response (numbers 31, 9, 11, 18 and 24), and the remaining five largest in diameter (numbers 4, 20, 26, 32 and 36). Acetate replicas were made of all these blisters, both pre- and post-bending, and no changes in cracking pattern were detected. Initially general ultrasonic scans were performed on tube #2, then detailed scans were performed on the ten blisters. The blisters were inspected using typical CIGAR-type equipment and procedures, as described in Section 3 below.

3.0 ULTRASONIC INSPECTION PROCEDURES

3.1 Equipment Used

The original pressure tube scanning rig was used, with a CIGAR head containing four CIGAR 10 MHz, 33 mm focussed ultrasonic probes. An Apple II Plus computer was used to drive the scanning rig, collect and display data. Thresholds and colours were set on the C-scans (area-amplitude contours) as follows: 0-25% full screen height (FSH) = green; 25-50% FSH = white; 50-100% FSH = red; and above 100% FSH = blue. For in-service CIGAR inspections, the nominal recording threshold is 50% FSH, though data of lower signal amplitudes can be examined in the isometric plots.

The main difference between this and previous pressure tube inspections was the use of a Krautkramer USIP 11 flaw detector instead of a Krautkramer-Branson KB6000 ultrasonic flaw detector due to a shortage of equipment. Later, the USIP 11 was compared with the KB6000 on blister #4 (see Section 4.2), and the comparison was satisfactory, at least in pulse-echo mode.

3.2 Calibration

Calibration was performed in two ways. First, maximum amplitudes on the axial probes were recorded from the manufacturers' standard circumferential reference notch. Second, power checks were performed as usual for CIGAR inspections. The double calibration procedure was used since the TRAC #2 tube was noticeably more bent and marked than virgin tubing. The results of the two calibration procedures were compatible with previous data/7/.

Calibration data are as follows: using the USIP 11, power checks in the TRAC #2 tube were 45-46 dB for the axial probes. Scanning levels were "standardized" at 68 dB (= power check + 23 dB), which is a typical CIGARette level/7/. Power checks in the reference tube were 39 dB, suggesting rougher surfaces on the TRAC tube. The signal amplitudes from the 0.076 mm (0.003") reference notch were 35 and 36 dB. Using the KB6000, power check in the TRAC tube was 12-13 dB, giving a CIGARette-type scanning level of 35 dB. For the clockwise probe using the USIP 11, power check in the TRAC tube was 34-36 dB, (32 dB in the reference tube), giving a scanning level of 60 dB.

3.3 General and Detailed Scans

Two sizes of C-scan were used. General scans were performed using a scan size of 45 degrees (approximately 45 mm) by 34 mm axially. This gave a raster step of 0.36 mm, or nearly one tenth of CIGAR's 3 mm general helical raster. The whole blistered area was mapped using general scans for the axial forward (AXF), axial back (AXB) and clockwise (CW) probes. Reflectors of interest in the general scans were positively identified by using the cursor feature in the Apple software, followed by damping reflectors on the outside surface.

Detailed scans used a 7 mm (approximately 7 degrees) by 4.8 mm axial scan size on each of the ten blisters for the AXF and AXB probes. This gave a raster step size of 0.05 mm. Detailed scans were positioned using the cursor, and reflectors positively identified by damping. Pitch-catch scans were also performed on the blisters to determine the amount of shadowing which occurred for defect characterization purposes. Then the signal from each blister was maximized using the cursor feature, and the amplitude recorded. Using the KB6000, B-scans were performed axially through blister #4.

Tube #2 had been previously scanned by Watson using a 1 mm raster step with both CIGAR and SLAR probes/5/.

4.0 RESULTS

4.1 General Scans

Figure 2 shows a composite scan using the AXF probe, with above threshold reflectors identified. Figure 3 shows a similar scan with the AXB probe, and Figure 30 a composite scan with the CW probe. The AXB probe corresponds to the SLAR scanning direction, as labelled on the tube.

The main features of the general scans are the large number of reflectors visible with the axial probes, including several blisters, and the lack of reflectors on the CW probe. Many of these reflectors proved to be marks on the tube. Reflectors in red or blue would be "called" by the CIGAR operator under normal circumstances.

Using the AXF probe and a 0.36 mm raster, the following blisters would have been called: #s 4, 6, 7, 31, 9, 11, 17, 18, 23, 24, 27, 32, and 36. Using the AXB probe, the following would have been called: #s 4, 6, 7, 31, 9, 11, 12, 18, 24, 32 and 36. Using the CW probe, only #31 would have been called. Replicas showed that cracking was predominately circumferentially. Previous work by Watson/5/ showed low amplitude CW probe reflections, below this 25% threshold. Blisters #s 4, 31, 9, 11, 18, 24 and 36 had been selected for metallography. Neither detailed scans nor replicas were performed on the remaining detected blisters (#s 6, 7, 12, 17 and 27).

4.2 Detailed Scans

Sample AXF probe scans are listed below. Figure 4 shows a detailed scan of blister #24 at the standard scanning level of 68 dB. Figure 5 shows a pitch-catch scan over the same area. Signal amplitudes dropped by 2-3 dB, but also increased in two nearby regions, which is contrary to Zr-II blister experience. (Later results on blister #4 suggested that this increase may be a feature of the USIP 11. However, it may be a feature of blister surface geometry.) Figure 6 shows blister #20 and Figure 7 blister # 11, both at CIGAR-type scanning levels. Figures 8 and 9 show blister #18 at standard scanning levels and at 12 dB lower gain respectively, showing the "regular" image of the reflector. Figures 12 and 13 show blister # 36 at standard scanning level, and 12 dB lower respectively, again showing a regular image.

Sample AXB probe scans are given below. Figure 14 shows the area containing blister #26 (selected for metallography) with no reflector detectable. Figure 15 shows a detailed scan of blister #24 at standard scanning level. Figures 16 and 17 show blister #18 at standard scanning level and 12 dB lower (compare with Figures 8 and 9 using AXF probe - only small differences are apparent). Figures 18 and 19 show blister #11 at the standard scanning level and 12 dB lower, and Figures 20 and 21 blister #9 under the same conditions. Figure 22 shows a detailed scan of blister #31, while Figure 23 shows a pitch-catch scan over the same area. As seen in Figure 5, areas of signal increase were observed, as well as a decrease of about 3 dB. Figures 24 and 25 show blister #4 at standard scanning level, and at 12 dB less gain.

Figure 26 shows blister #4 using the AXB probe and the KB6000. Comparison with Figure 24 shows only a slight difference in response, mainly in signal strength

(ignore the slight location change). The small amount of image change between Figures 24 and 26 could easily have arisen from changing probe rather than flaw detector, and indicates that the USIP 11 was behaving similarly to the KB6000 in pulse-echo mode. Figure 27 shows the same area at 12 dB less gain, and comparison with Figure 25 also indicates the USIP 11 was performing reasonably. Figure 28 shows a pitch-catch scan over blister #4, but only signal decreases were observed in contrast with the results from the USIP 11. This suggests that the USIP 11 is not the same as the KB6000 in all testing modes. Also, the USIP 11 was running near maximum gain, whereas the KB6000 was not. Figure 29 shows an axial B-scan through blister #4 at the standard scanning level using the AXB probe, showing only one distinct reflector.

No detailed scans were performed using the CW probe.

4.3 Maximum Blister Amplitudes

Table 1 shows maximum signal amplitudes and crack lengths estimated from the replicas. These data are plotted in Figure 31, where a rough correlation between crack length and signal amplitude can be seen. There is some uncertainty in the data from the replicas, which will be resolved if and when the blisters are examined metallographically. Signal amplitudes are dependent on several factors, such as crack skew, crack tilt and crack transparency as well as crack size. Consequently a simple correlation between amplitude and crack length would not be expected.

4.4 Pitch-Catch for Characterization

Axial probe pair pitch-catch scans were performed on most of the blisters using the USIP 11. The scans were difficult to present using the standard C-scan format since only small changes in amplitude occurred, and the best information was obtained by watching the CRT trace for fluctuations. The results can be summarized as follows. Typical amplitude drops on known cracked blisters were 4-5 dB, though drops of 6+ dB were also observed. Even blisters with low pulse-echo response showed amplitude drops of 2-3 dB, suggesting blister surface contours could be a factor. The estimated dB drops are shown in Table 1, along with the pulse-echo data and replica crack lengths.

The pitch-catch results are not inspiring. There was little correlation between dB drop and pulse-echo amplitude or crack length. There was considerable variation from scan to scan, and scans were not particularly repeatable, even under nominally identical conditions. Using the USIP 11, increases as well as decreases were observed, which is contrary to in-service experience. On blister #4, scanned by both the USIP 11 and the KB6000, the results from the two flaw detectors were different: the KB6000 showed no signal increases, and only 2-3 dB signal drop, not the 4-5 dB drop detected by the USIP 11.

There are two tentative conclusions from this. First, the USIP 11 appears to be overstretched for pitch-catch scans. Second, the pitch-catch characterization technique appears to have difficulty differentiating small cracked blisters from uncracked blisters (though there is always some uncertainty in the replica information).

5.0 DISCUSSION

5.1 Blister Response

These Zr-Nb blisters showed surprisingly regular profiles in comparison with the Zr-II blisters from Pickering 1 and 2 previously examined at CRNL by Research. Figures 32 and 33 show two sample scans from P1 K05 Zr-II blister reproduced from /8/ for comparison. This difference in image can be tentatively explained by the cracking behaviour of the blisters and their relative sizes.

Both the replicas on the TRAC tube blisters and metallography on the P1 and 2 tubes indicate a crazy paving-type of cracking/9/. With the large Zr-II blisters, the ultrasonic beam size (about 1.5 mm in diameter) is considerably smaller than the blister, so different portions of the cracking will be imaged at different probe positions. Consequently, factors such as local crack configuration and orientation will give some fluctuations in amplitude over the whole blister. For the Zr-Nb blisters, the cracks are smaller than the beam width, so the whole blister is imaged at once. Consequently, the Zr-Nb blisters act more as point sources, and the C-scan images look much more regular, almost like a small notch. In contrast, the larger Zr-II blisters can be viewed as a series of isolated point sources, of different reflectivity.

The signal amplitudes from the smaller Zr-Nb blisters are similar to those from the much larger Zr-II blisters /7/, with the highest amplitudes roughly the same as a 0.076 mm (3 thou) notch on the outside surface. As mentioned above, the probe beam only covers a portion of the larger blisters, while the smaller blisters cover most of the beam area. Consequently, similar signal amplitudes are not unexpected, since the actual amplitudes will be dictated by local crack orientation, skew and transparency, not by crack size.

5.2 Zr-Nb Blister Detectability

One key question arising is "What is the probability of detecting a Zr-Nb blister during a CIGAR general helical scan?" The results of this work indicate that a cracked Zr-Nb blister gives a signal amplitude well above the normal recording threshold. Thus, if a CIGAR probe beam crosses a blister at the maximum amplitude position, the blister will be detected. However, the range where the signal is above threshold is only a millimetre or two (see Figures 4, 6, 8, 10-12 for examples).

Since CIGAR uses a 3 mm raster step for its general helical scan, there is a finite probability that the beam will step over a given isolated blister. With a 1 mm step, the probability of completely missing a blister is obviously low, but even at this raster step, CIGAR would be unlikely to obtain the maximum signal amplitudes/5/. It is apparent that probability of detection is primarily dictated by raster step size, not by signal-to-noise ratio. It is also a function of blister crack size.

Watson/5/ performed SLAR and CIGAR scans on this tube using a 1 mm raster step. These results measured dynamic signal amplitudes from individual blisters from the scan, not by peaking up on them in static mode, and showed that the detectability of SLAR and CIGAR probes were similar. As discussed above, the CIGAR

probe signal amplitudes will depend heavily on where the beam crosses individual blisters, so the results will be statistical and non-maximized. Thus, Watson's results will not be the same as these very detailed scans with maximized signals since two very different tests were performed. Further work is in progress to evaluate the effect of raster size on blister detectability.

6.0 CONCLUSIONS

1. Cracked TRAC #2 tube Zr-Nb blisters are readily detectable using CIGAR-type pulse echo ultrasonics (assuming the replica results are reasonable estimates of crack lengths).
2. Maximum signal amplitudes from the largest reflectors were up to 28 dB above the nominal recording threshold.
3. The detailed C-scan images of individual blisters show very regular profiles, in contrast to the larger Zr-II blisters from Pickering.
4. Blister detectability for CIGAR ultrasonics will be primarily dictated by raster step size, not by signal-to-noise ratio.
5. Pitch-catch appears to be an unreliable technique for differentiating small cracked blisters from other reflectors, at least with a USIP 11 flaw detector.
6. The differences between the images from the larger Zr-II blisters in Pickering 1 and 2 and these TRAC Zr-Nb blisters can be tentatively attributed to relative blister/beam sizes.

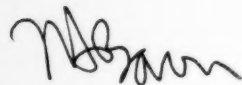
7.0 RECOMMENDATION

Work on blister detectability as a function of raster size should continue.

8.0 ACKNOWLEDGEMENTS

The blistered tube was loaned by TRAC. Information on the ultrasonic testing of the tube was supplied by Mr. N.J. Watson.

Reviewed:



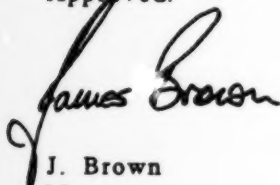
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3. M.D.C. Moles and J.W. Huggins, AECL/Ontario Hydro Fuel Channel Technology Seminar, Oakville, Ont. November 12-14, 1985.
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5. N.J. Watson, CNS Report No. 904-SLAR-76660 P, October 17, 1986.
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8. M.D.C. Moles and A.L. Allen, OHRD Report No. 84-179-K, June 29, 1984.
9. G.D. Moan, Memos to N.J. Watson, AECL-SP File No. 40-31110-300-000, August 6 and 10, 1987.

TABLE 1

**Maximum Signal Amplitudes From the Ten Blisters,
Plus Crack Lengths Estimated From Replicas**

Blister #	AXB Probe (dB Above Threshold)	AXF Probe (db Above Threshold)	Estimated Crack Length (mm)	Estimated Signal Drop in Pitch-Catch Mode (dB)
4	+22	-	*	4-5 using USIP, 2-3 using KB6000
31	+ 8	-	0.85	6
9	+23	+28	0.90	6+
11	+22	+24	1.06	4-6
18	+25	+22	1.15	5-6
20	+24	+18	0.75	2-3
24	+13	+16	0.32	2-6
26	-10	-	0.0	0-3
32	+ 4	-	0.0	2
36	-	+26	0.70	6

*Initial investigation showed no cracks in blister #4. Subsequent re-examination of the replica showed a possible crack about 0.4 mm long. Metallography or another replica should resolve this issue.

Star
Scanning
Direction

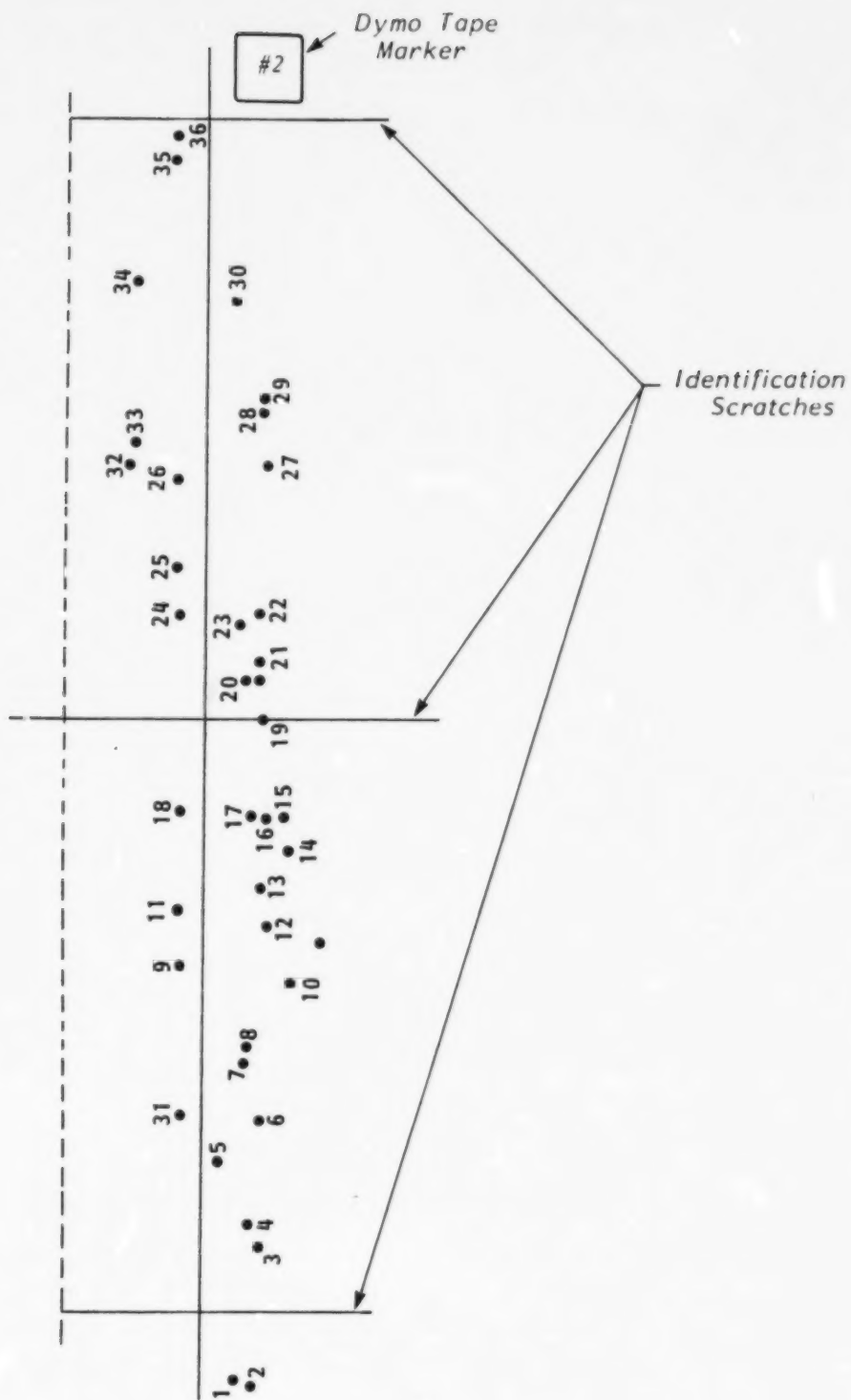


FIGURE 1
TRACING OF BLISTER LOCATIONS ON TRAC TUBE #2

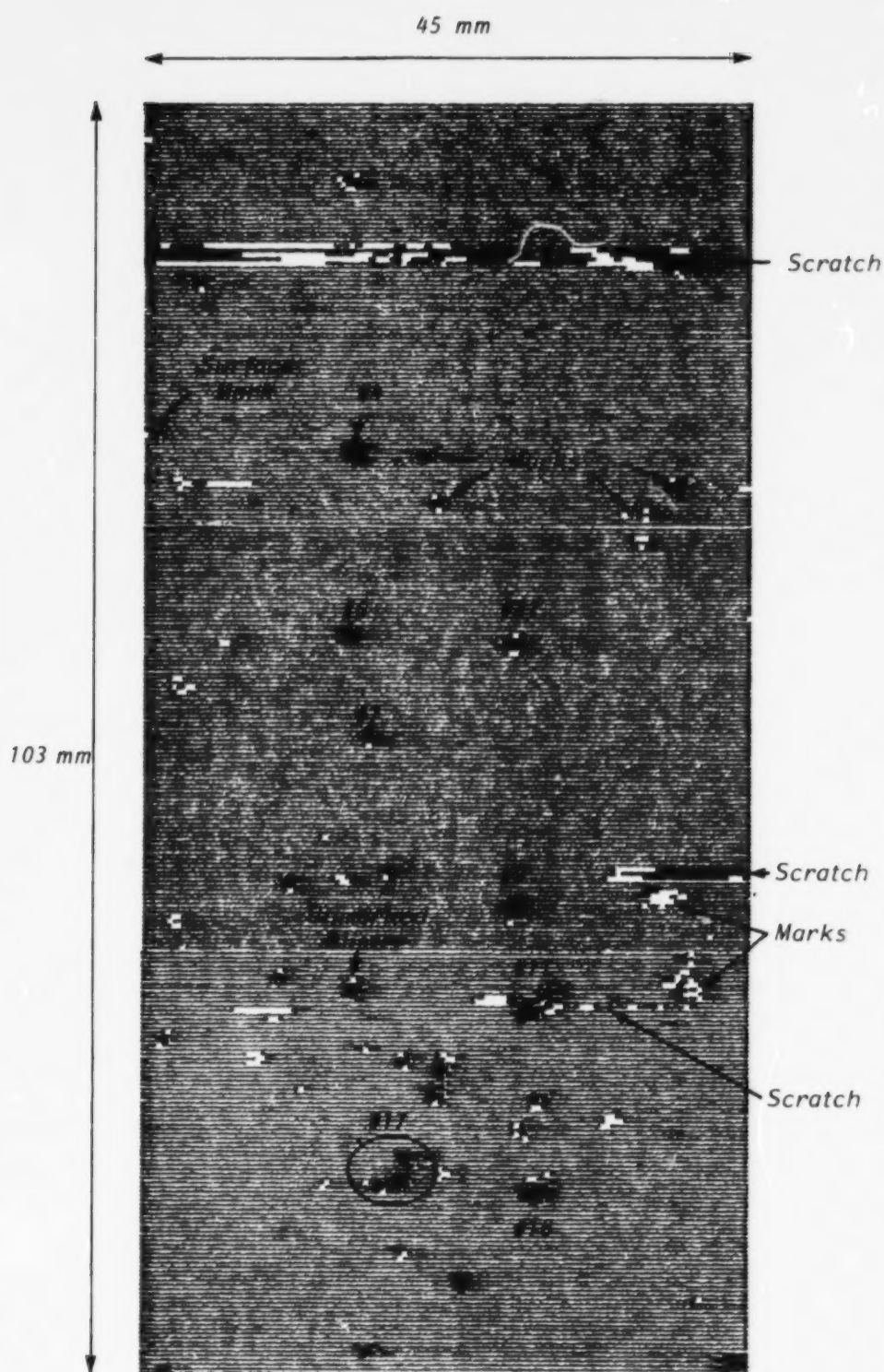


FIGURE 2(a)
PART OF GENERAL SCAN OF TRAC #2 PT
WITH BLISTERS AND OTHER REFLECTORS
MARKED, AXF PROBE AT TYPICAL CIGAR LEVELS

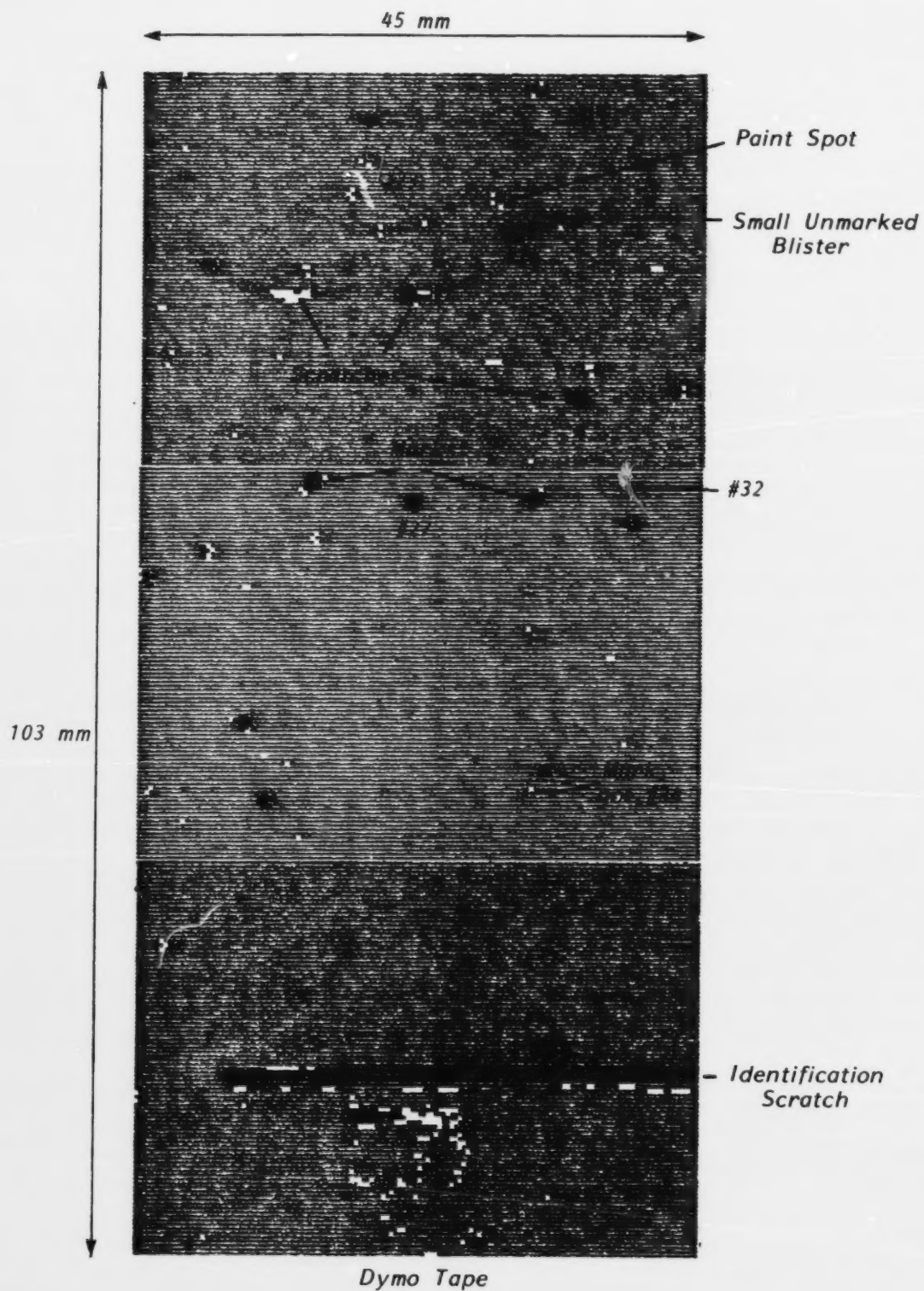


FIGURE 2(b)
BALANCE OF GENERAL SCAN OF TRAC #2
PT USING AXF PROBE

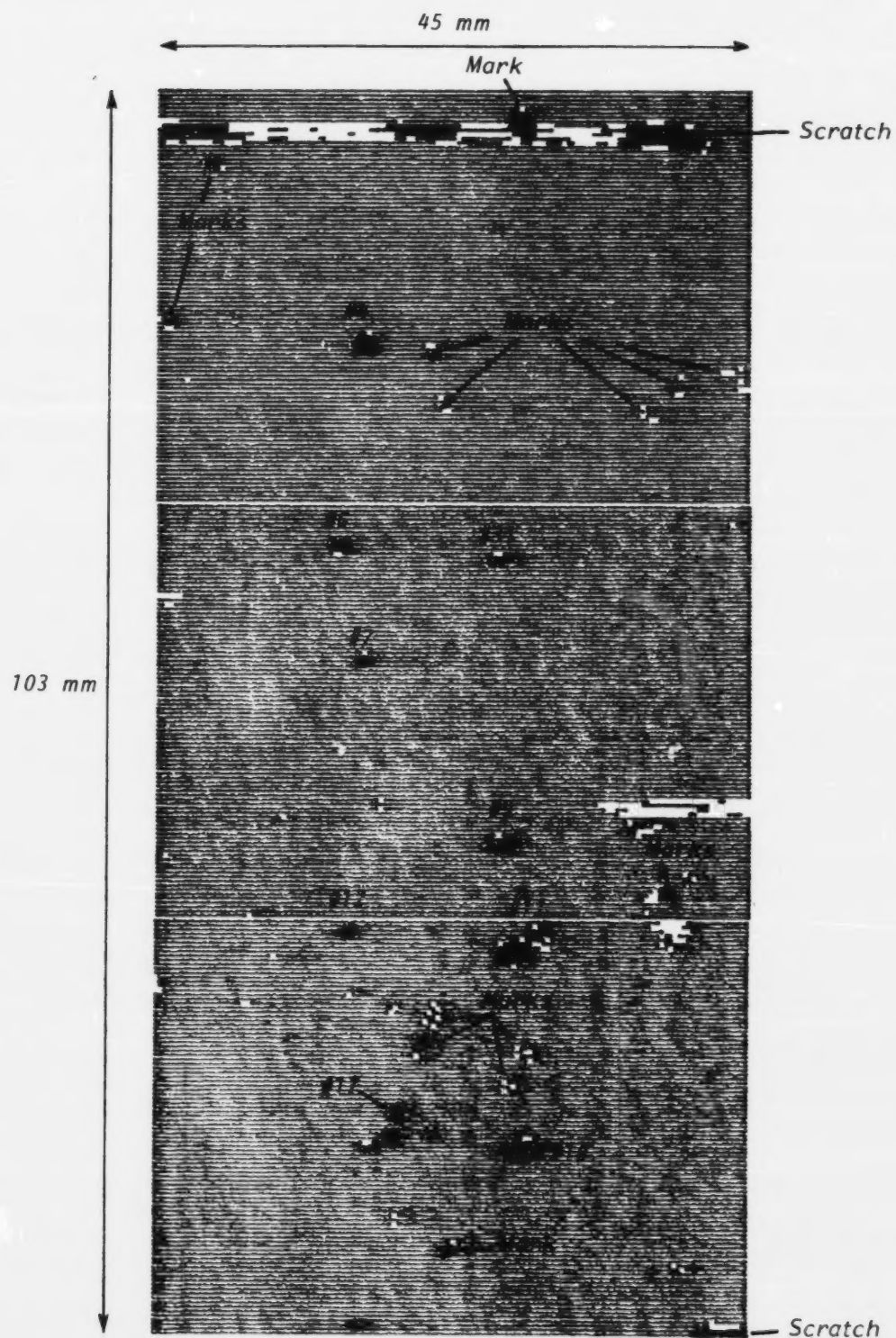


FIGURE 3(a)
PART OF GENERAL SCAN USING AXB PROBE

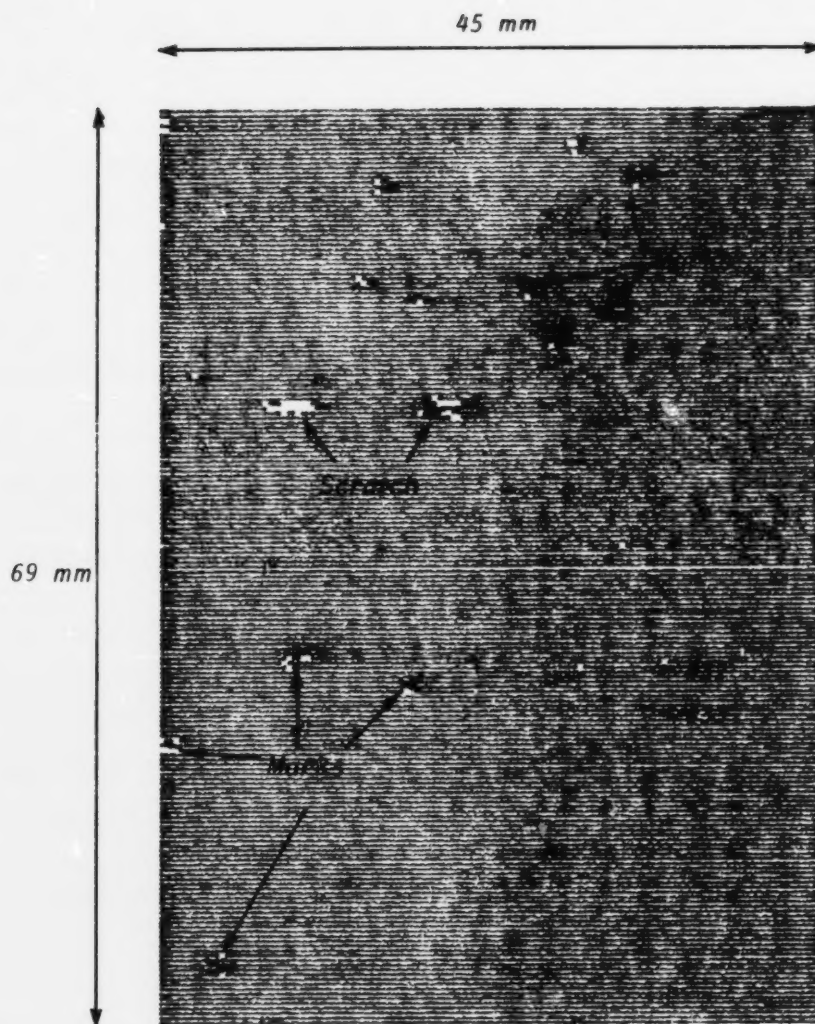


FIGURE 3(b)
BALANCE OF GENERAL SCAN USING AXB PROBE
[NOTE: SCAN WITH BLISTER #3b MISSING]

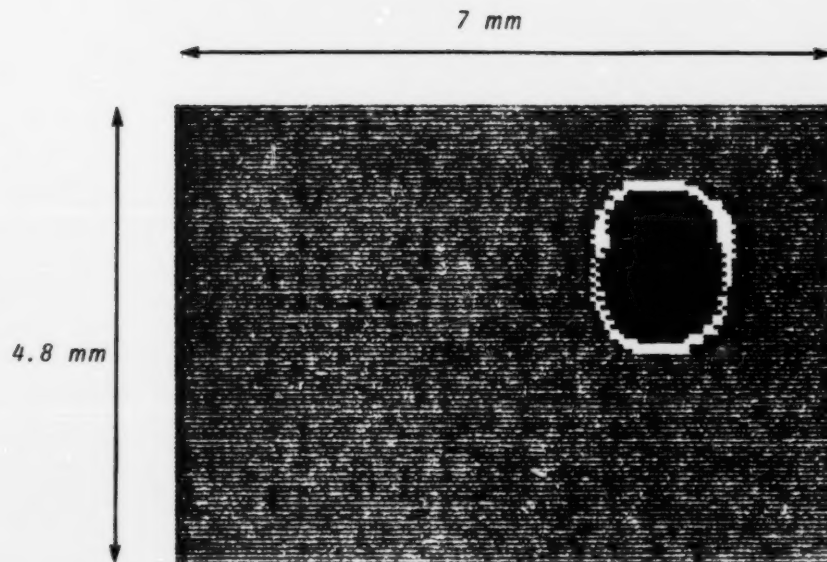


FIGURE 4
DETAILED SCAN OF BLISTER #24 AT STANDARD SCANNING
LEVELS (68dB), SHOWING SIGNALS WELL ABOVE
100% FSH AXF PROBE

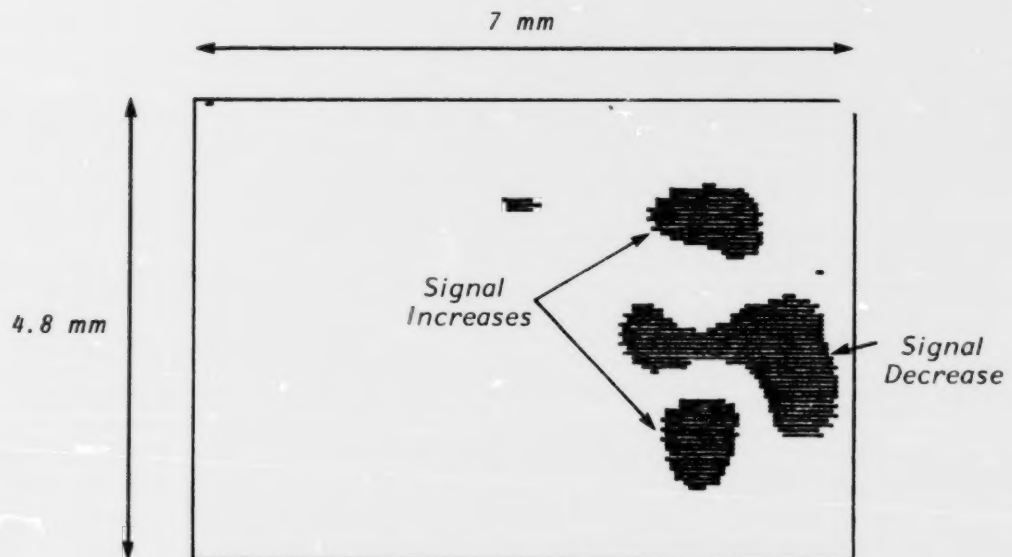


FIGURE 5
DETAILED PITCH-CATCH SCAN OVER BLISTER #24
USING USIP 11, SHOWING AREAS OF SIGNAL
INCREASE AND DECREASE

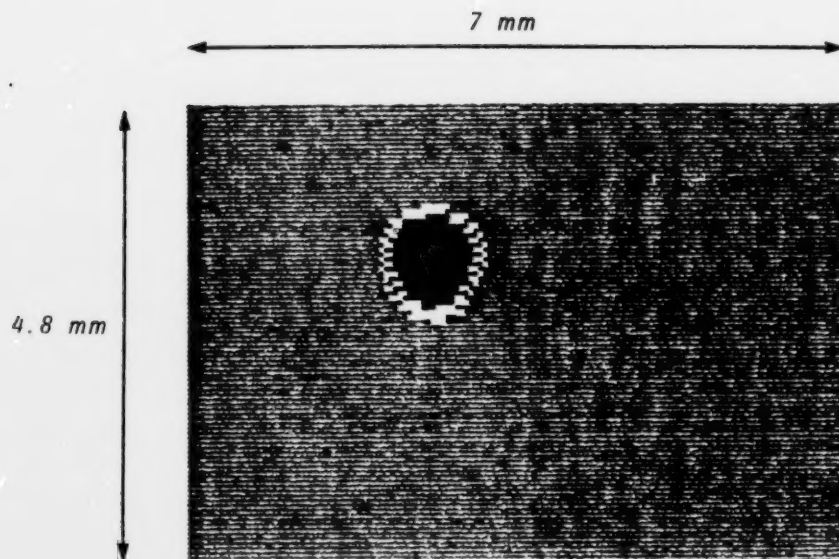


FIGURE 6
DETAILED SCAN OF BLISTER #20 AT
STANDARD SCANNING LEVEL (68dB) AXF PROBE

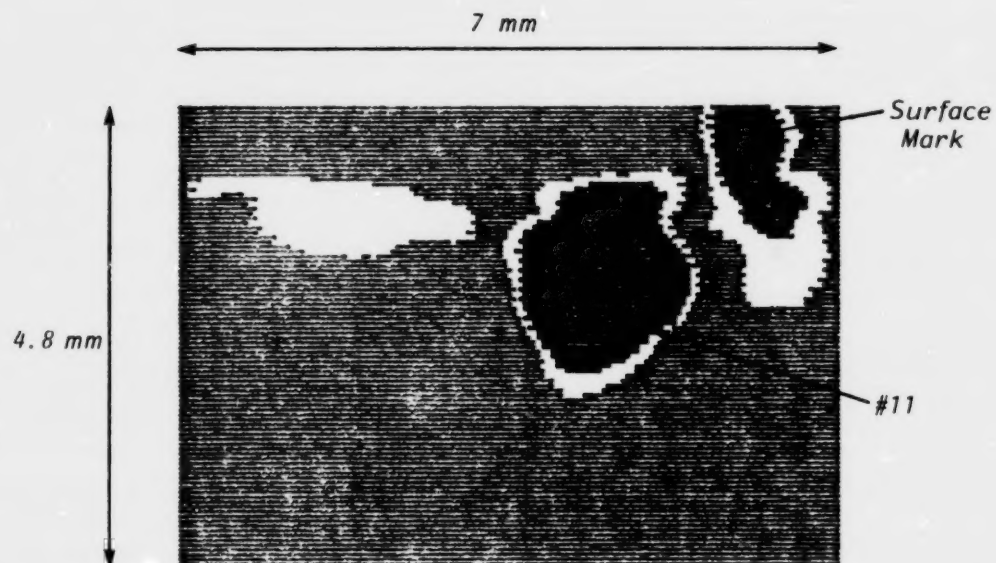


FIGURE 7
DETAILED SCAN OF BLISTER #11 AT
STANDARD SCANNING LEVEL (68dB) AXF PROBE

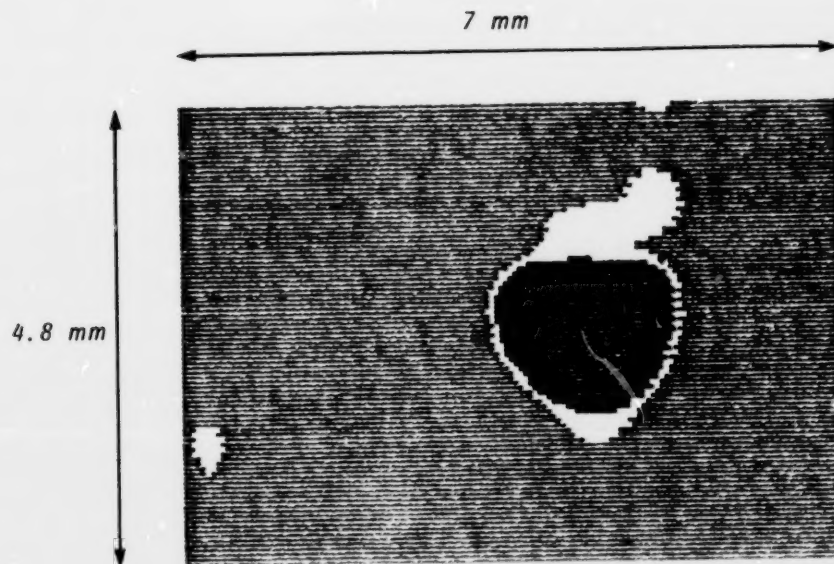


FIGURE 8
 DETAILED SCAN OF BLISTER #18 AT
 STANDARD SCANNING LEVEL (68dB = POWER CHECK
 + 23 dB) AXF PROBE

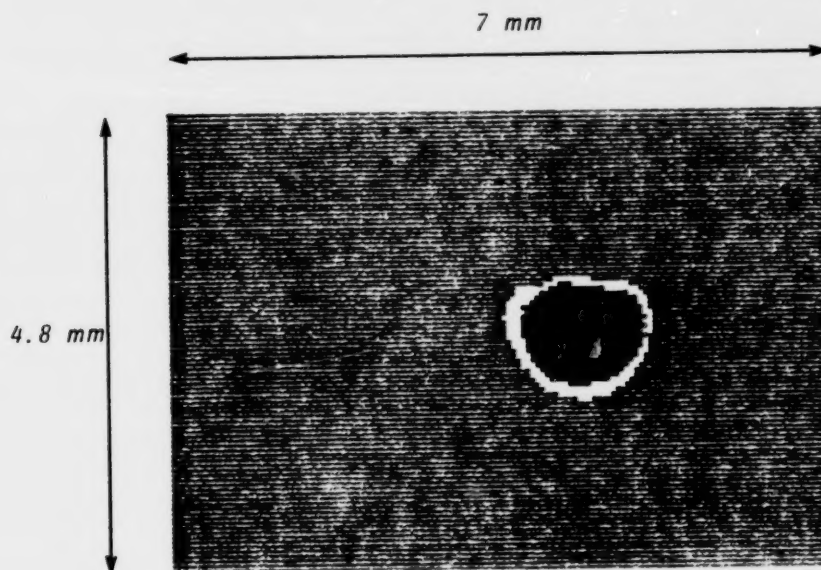


FIGURE 9
 DETAILED RE-SCAN OF BLISTER #18, AT A
 SCANNING LEVEL (12dB) BELOW THAT IN FIGURE 8
 (56dB = POWER CHECK + 11dB) AXF PROBE

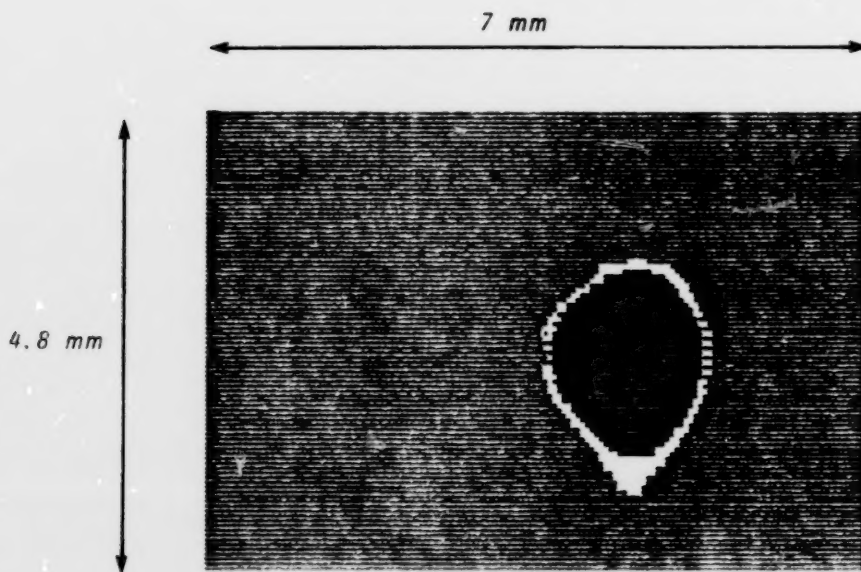


FIGURE 10
DETAILED SCAN OF BLISTER #9 AT
STANDARD SCANNING LEVEL AXF PROBE

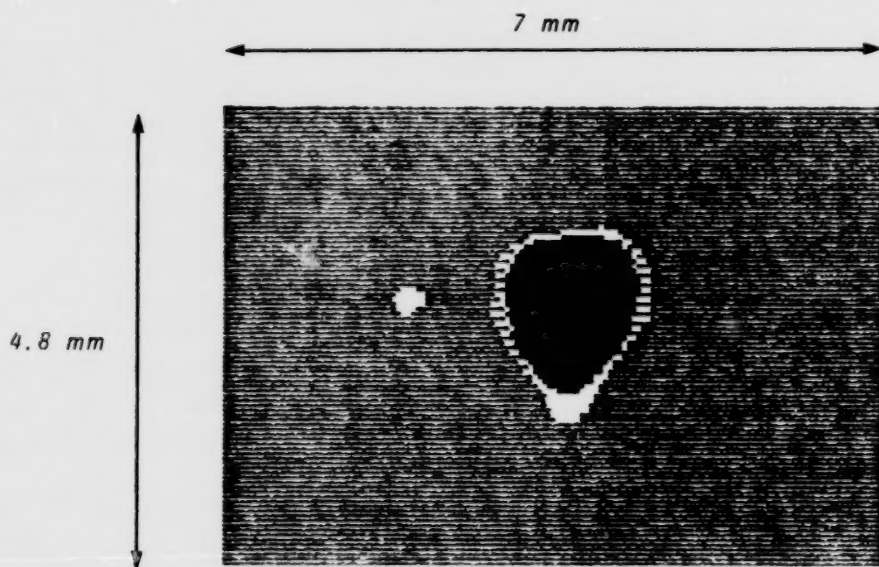


FIGURE 11
DETAILED SCAN OF BLISTER #4 AT
STANDARD SCANNING LEVEL (68dB) AXF PROBE

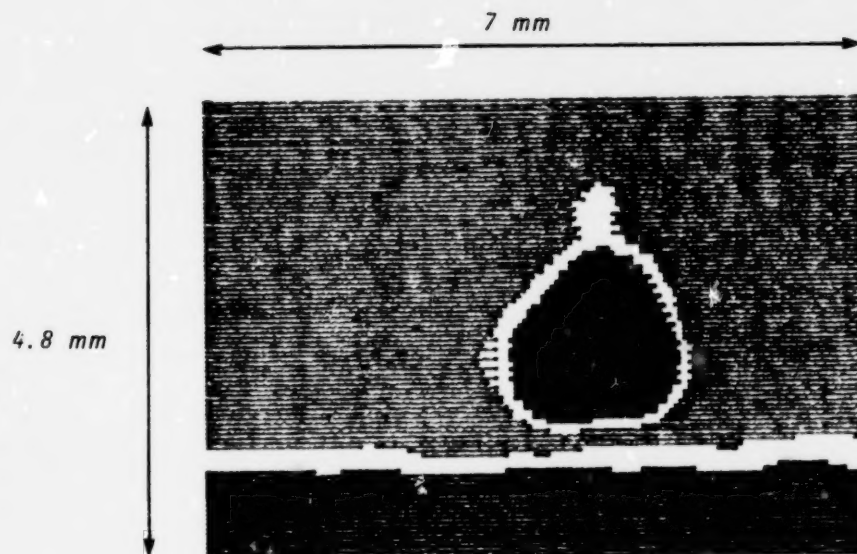


FIGURE 12
DETAILED SCAN OF BLISTER #36 AT
STANDARD SCANNING LEVEL (68dB) AXF PROBE

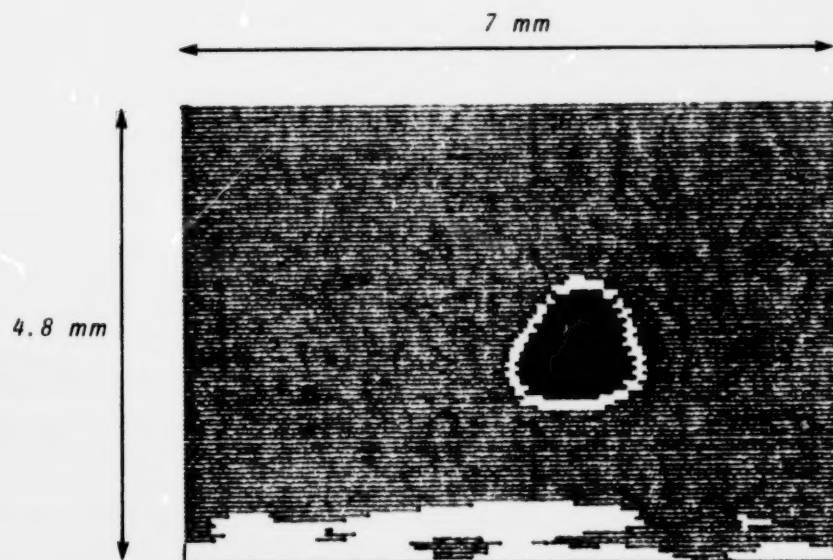


FIGURE 13
DETAILED RE-SCAN OF BLISTER #36 AT
12dB BELOW FIGURE 12
(56dB = PC + 11dB)

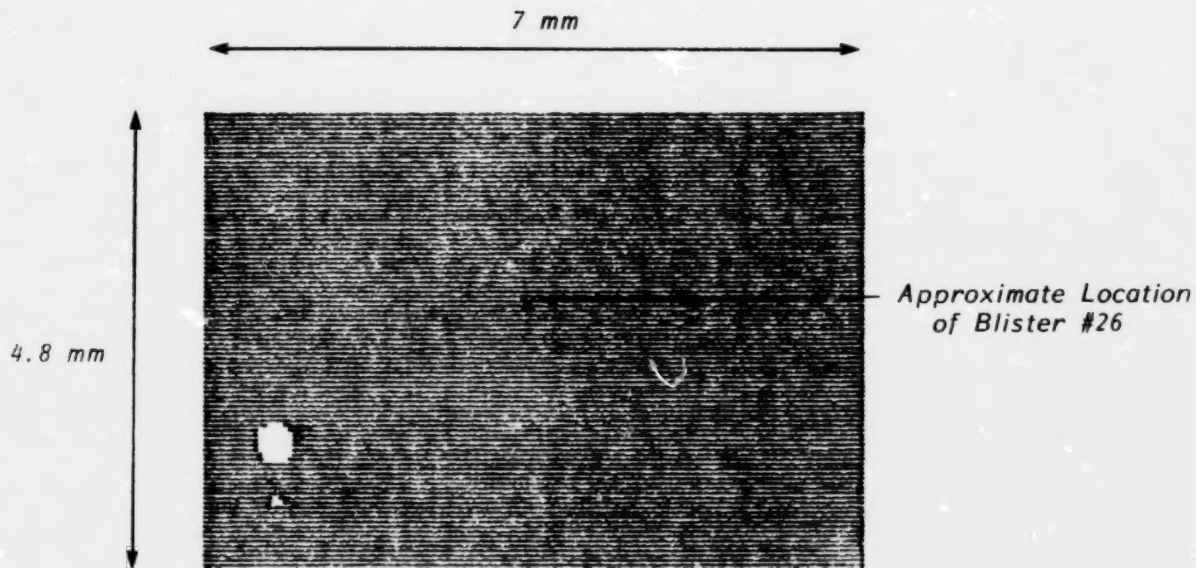


FIGURE 14
DETAILED SCAN OF BLISTER #26 USING
AXB PROBE AT STANDARD SCANNING LEVEL (68dB)

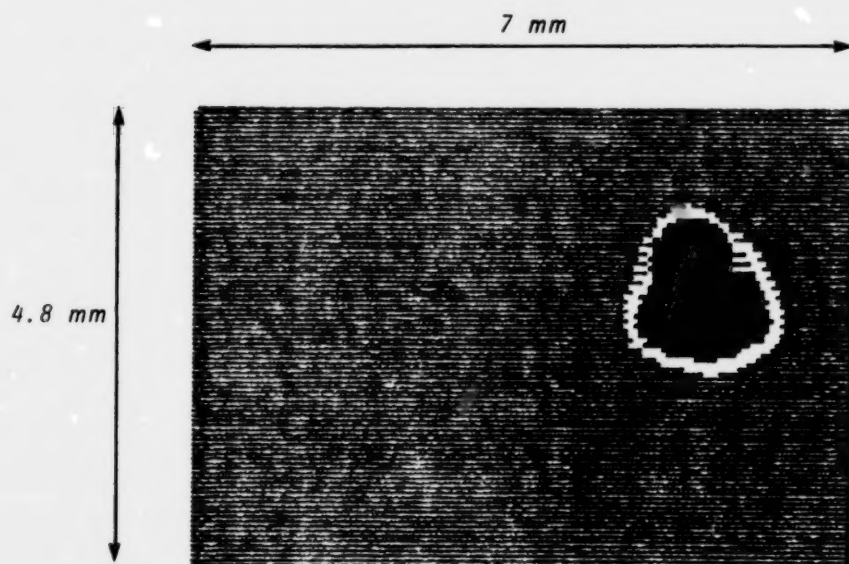


FIGURE 15
DETAILED SCAN OF BLISTER #24 USING
AXB PROBE AT STANDARD SCANNING LEVEL (68dB)

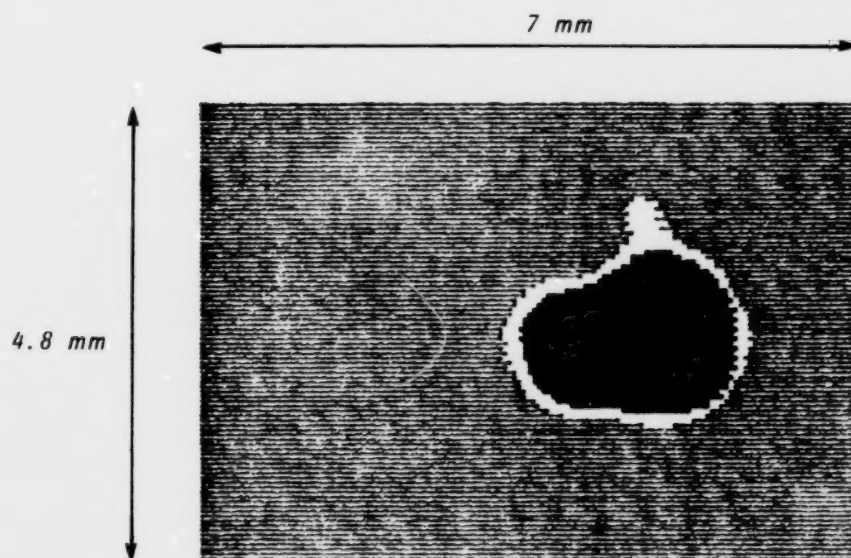


FIGURE 16
DETAILED SCAN OF BLISTER #18 AT STANDARD
SCANNING LEVEL (68dB = PC + 23dB) AXB PROBE

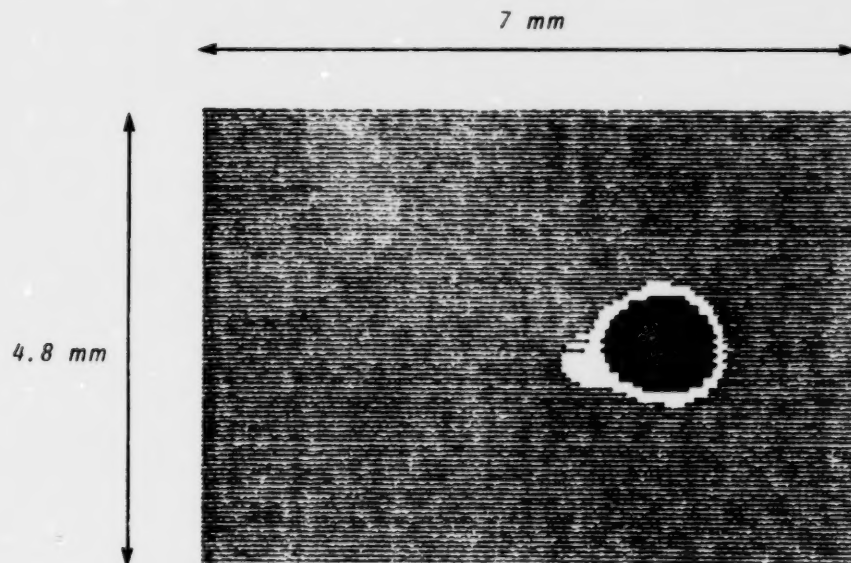


FIGURE 17
DETAILED RE-SCAN OF BLISTER #18 AT
56dB (= PC + 11dB) AXB PROBE

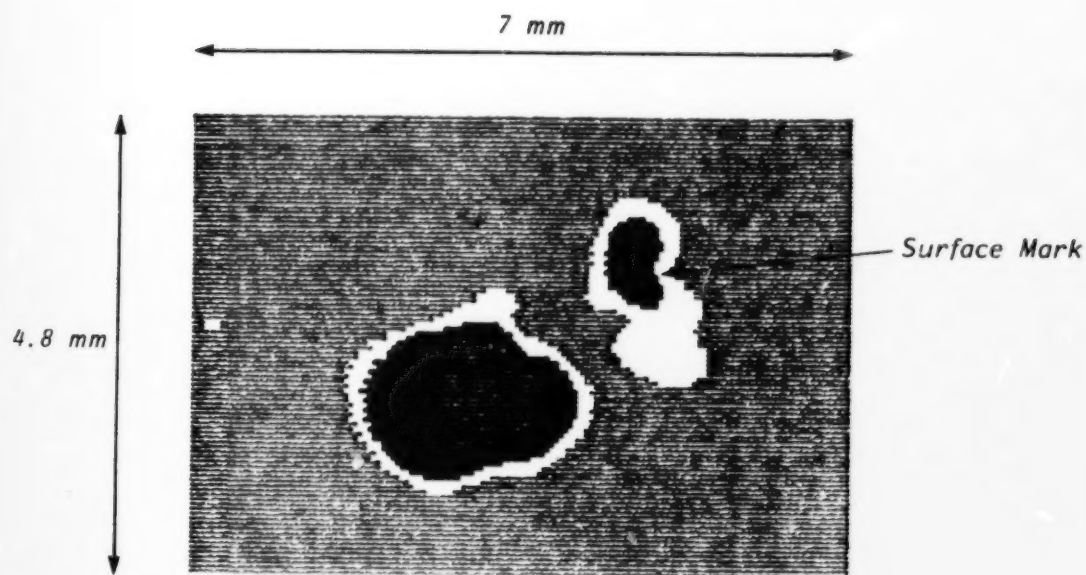


FIGURE 18
DETAILED SCAN OF BLISTER #11 AT
STANDARD SCANNING LEVEL (68dB) AXB PROBE

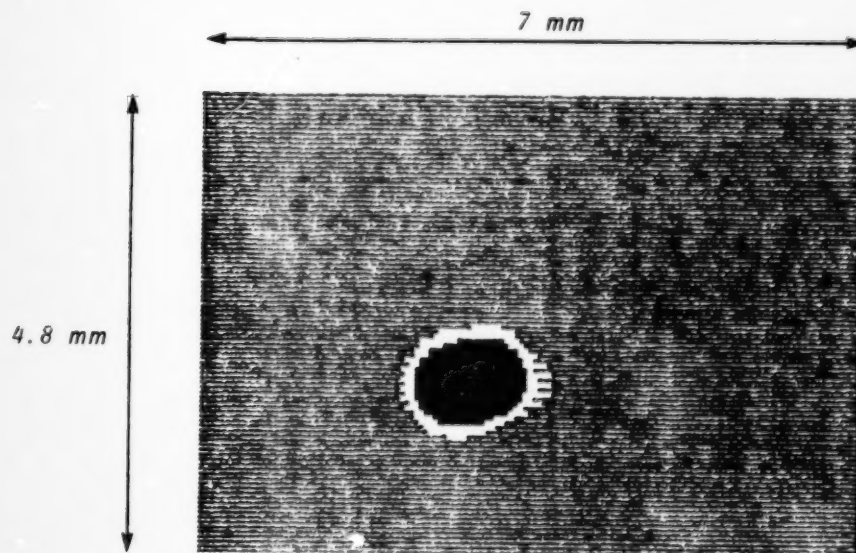


FIGURE 19
DETAILED RE-SCAN OF BLISTER #11 AT
56dB (= PC + 11dB) AXB PROBE

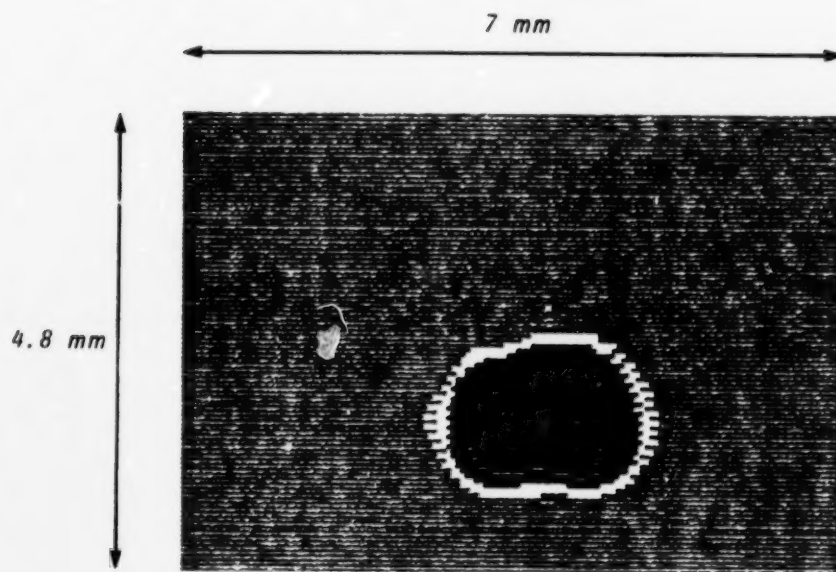


FIGURE 20
DETAILED SCAN OF BLISTER #9 AT
STANDARD SCANNING LEVEL (68dB) AXB PROBE

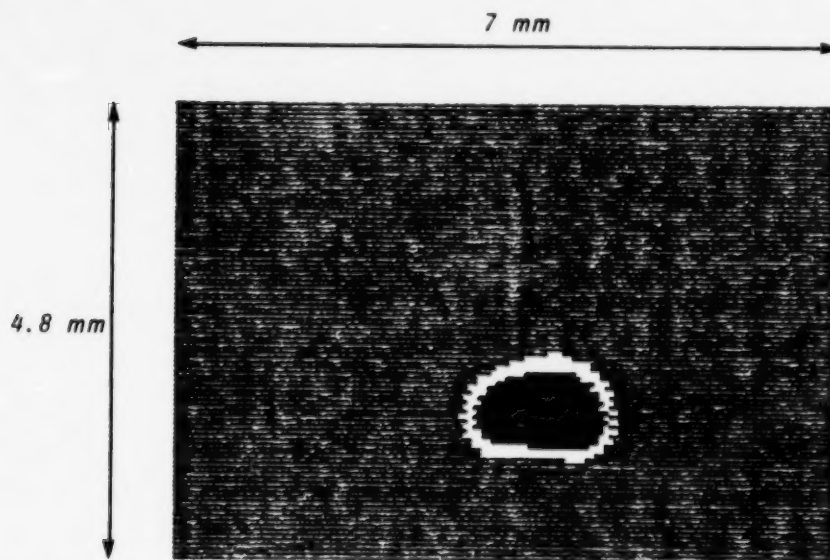


FIGURE 21
DETAILED RE-SCAN OF BLISTER #9 AT
56dB (= PC + 11dB) AXB PROBE

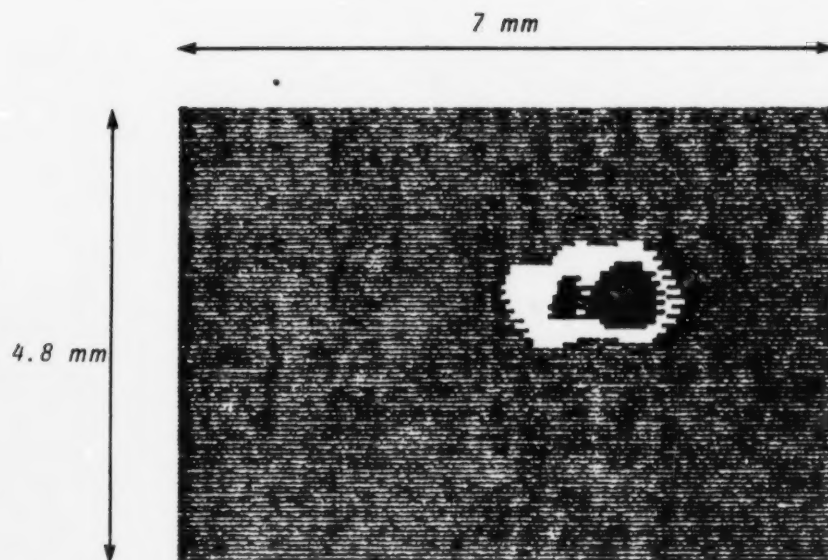


FIGURE 22
DETAILED SCAN OF BLISTER #31
AT 68dB AXB PROBE

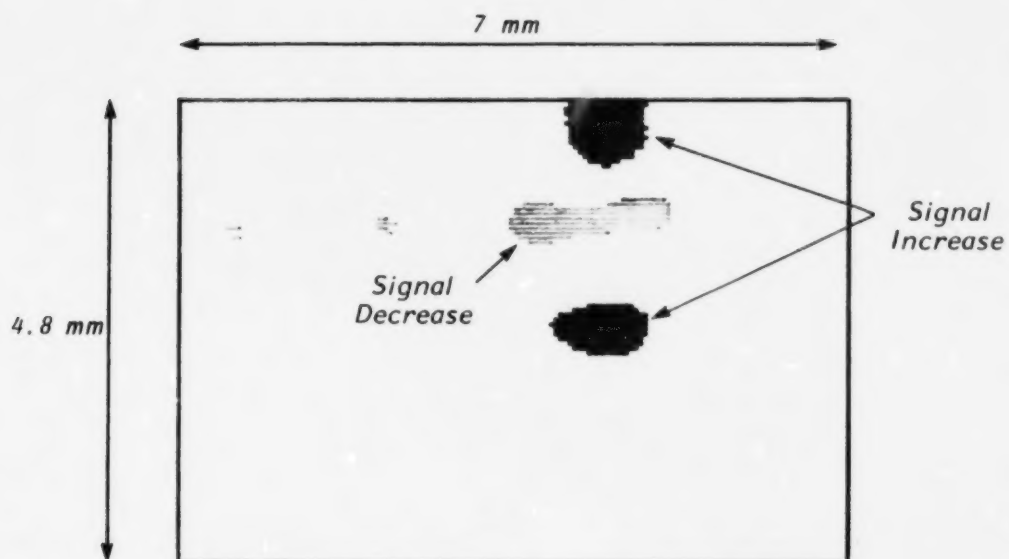


FIGURE 23
PITCH-CATCH SCAN OF BLISTER #31 SHOWING
AREAS OF SIGNAL INCREASE AND DECREASE
USING USIP 11

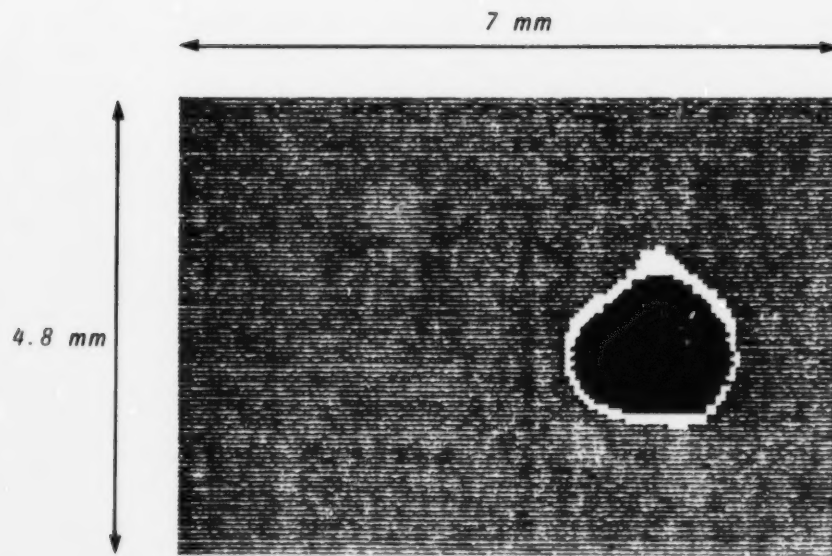


FIGURE 24
DETAILED SCAN OF BLISTER #4 AT
68dB USING USIP 11 AND AXB PROBE

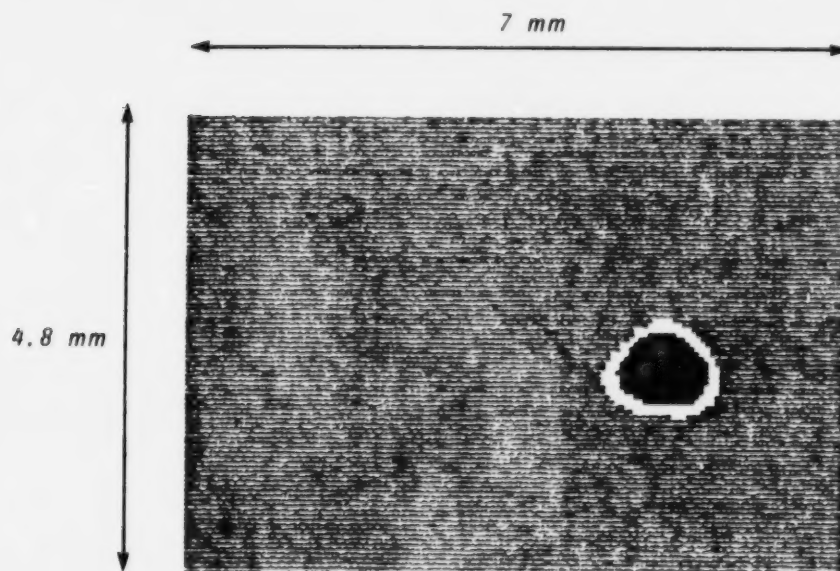


FIGURE 25
DETAILED RE-SCAN OF BLISTER #4 AT
56dB (= PC + 11dB) USING USIP 11 AND AXB PROBE

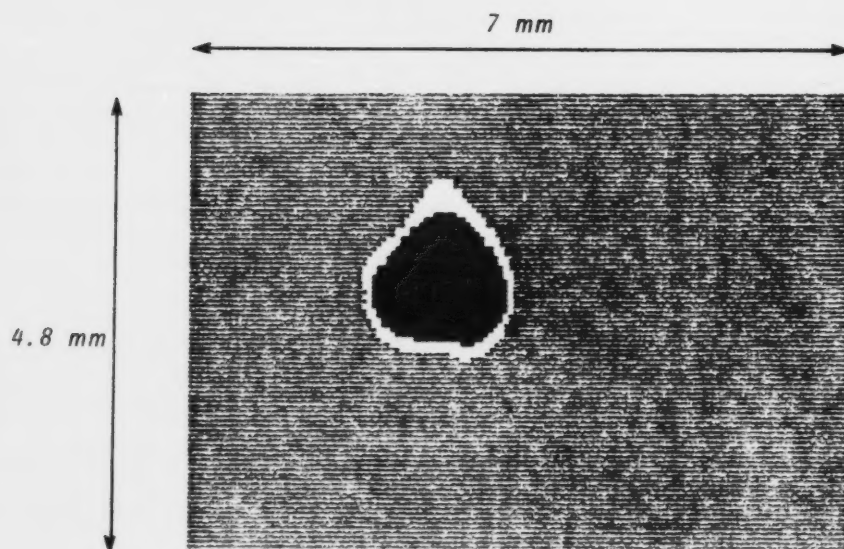


FIGURE 26
DETAILED SCAN OF BLISTER #4 USING KB 6000
AT STANDARD CIGAR-TYPE SCANNING LEVEL
AND AXB PROBE (35dB = PC + 23dB)

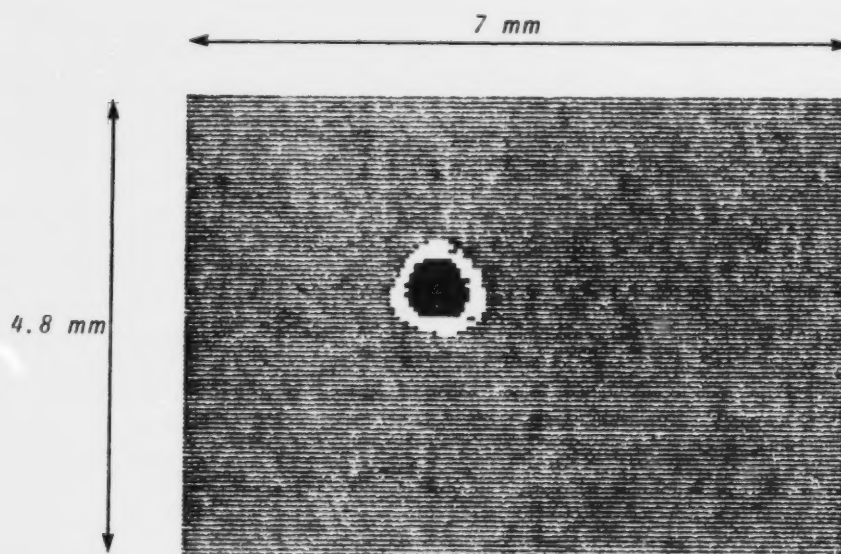


FIGURE 27
DETAILED RE-SCAN OF BLISTER #4 USING
KB 6000 AT 23dB (= PC + 11dB)

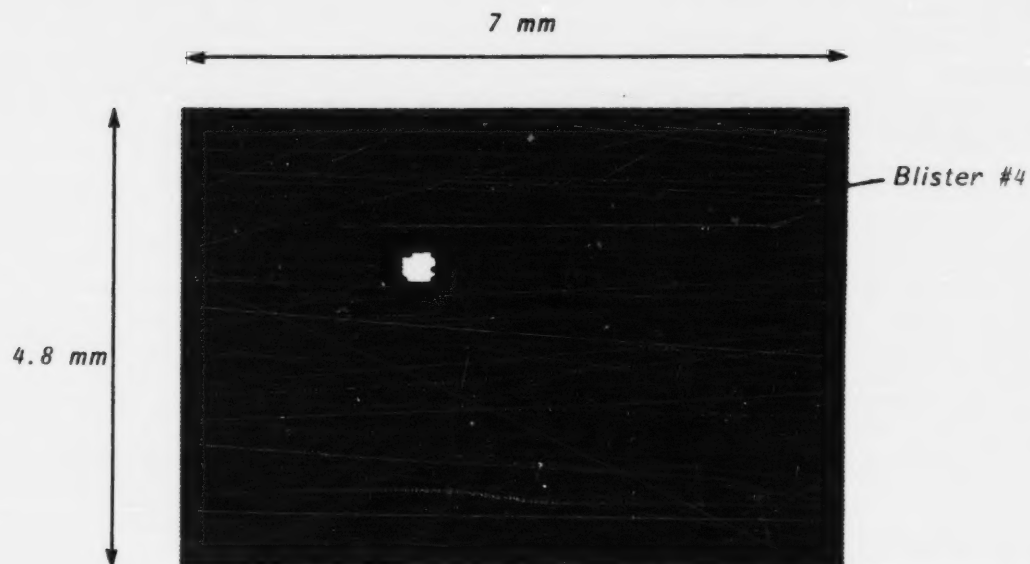


FIGURE 28
PITCH-CATCH SCAN OF BLISTER #4
USING KB 6000 AT 16dB

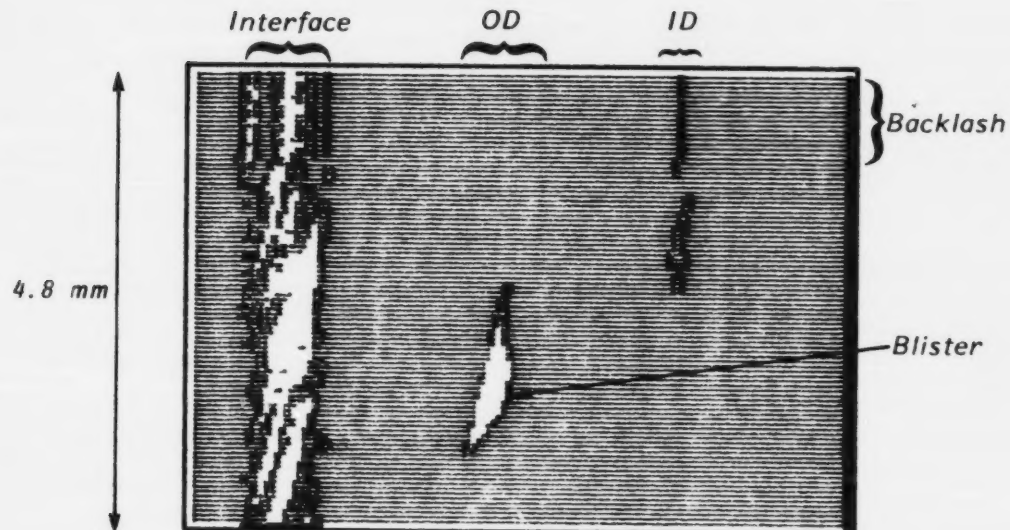


FIGURE 29
B-SCAN OF BLISTER #4 AT 35dB USING
AXB PROBE. AXIAL SCANNING DIRECTION

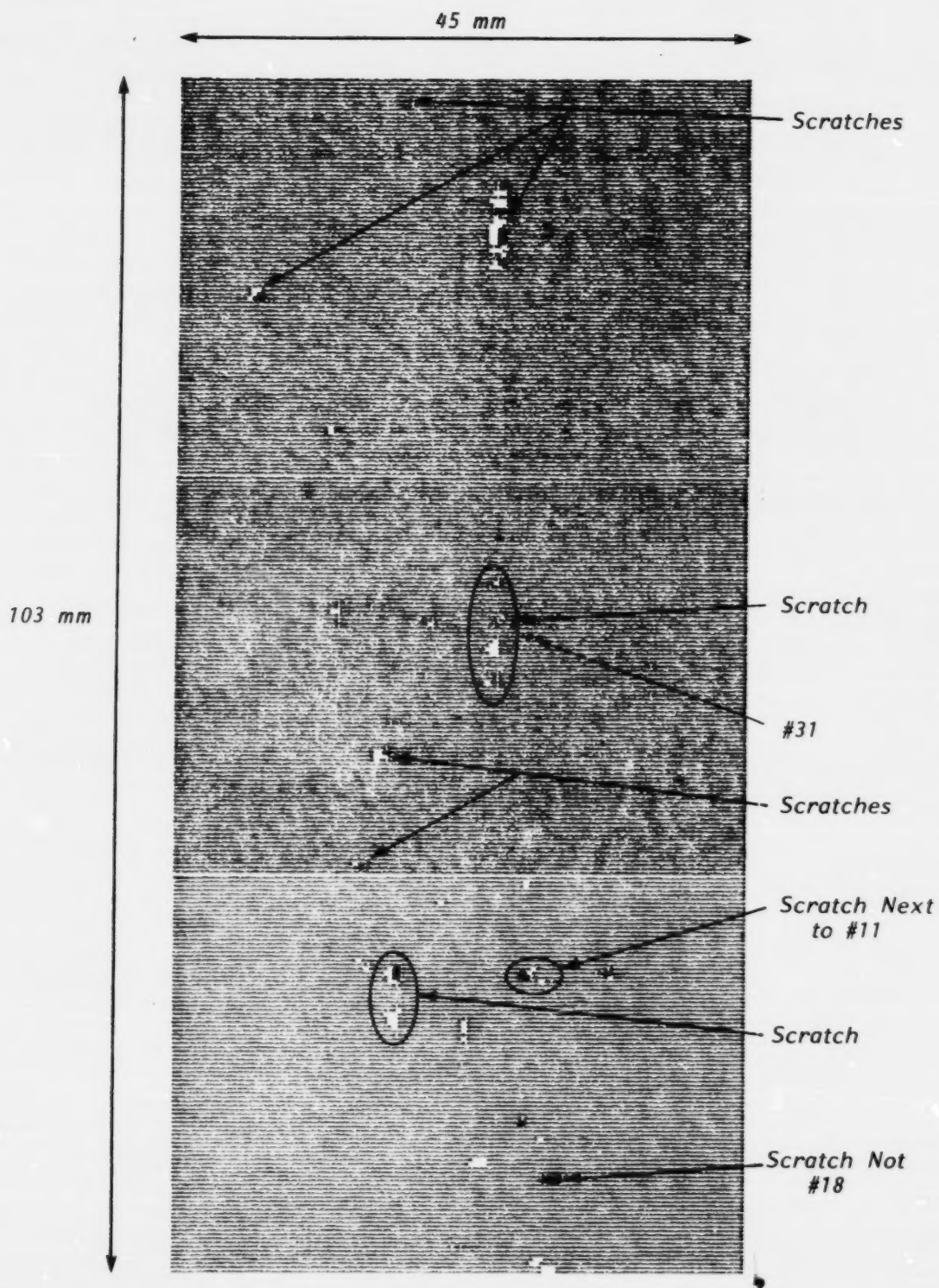


FIGURE 30(a)
PART OF GENERAL SCAN USING CW PROBE AT
STANDARD SCANNING LEVEL (60dB)

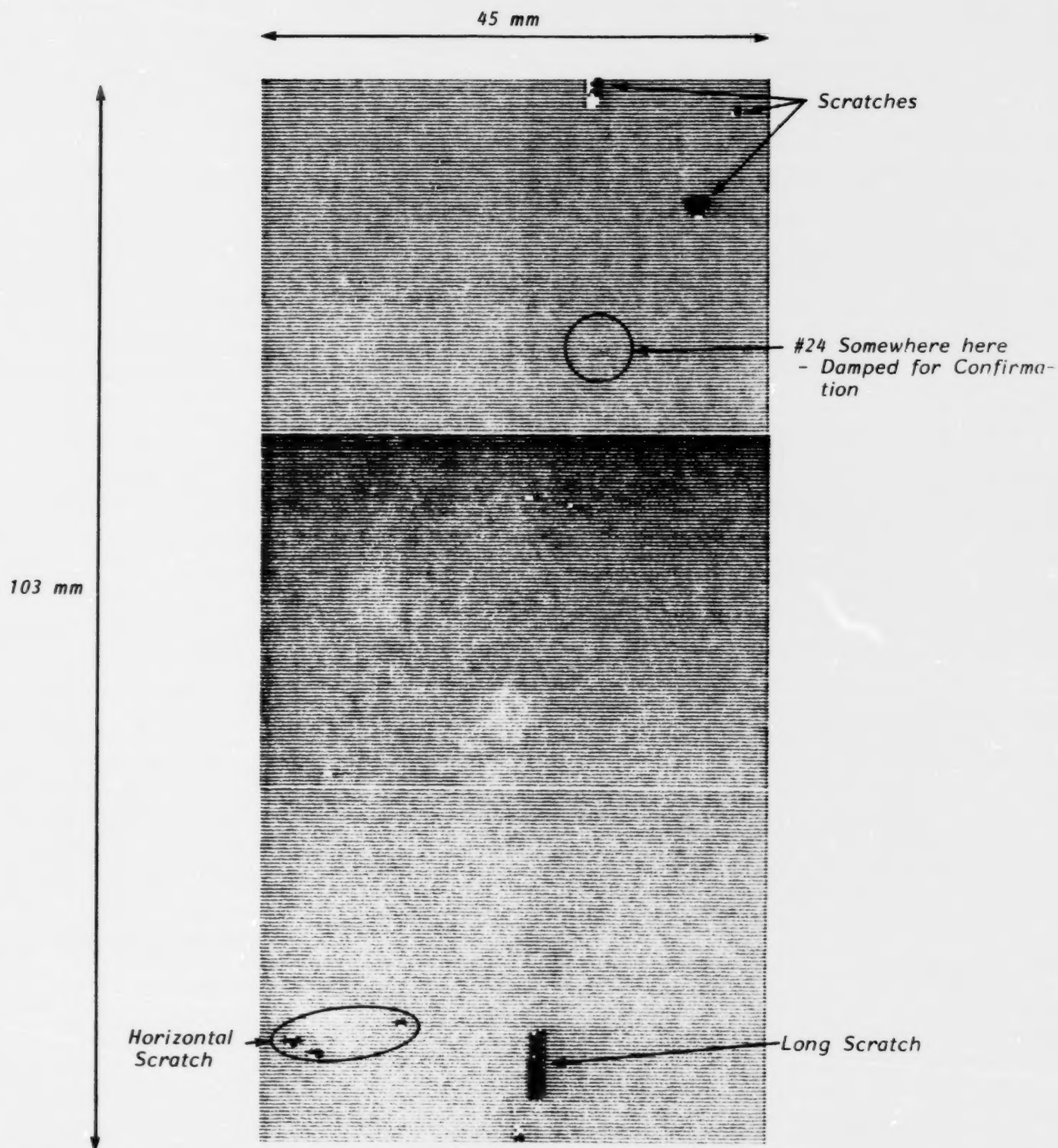


FIGURE 30(b)
REMAINDER OF GENERAL SCAN USING
CW PROBE AT 60dB

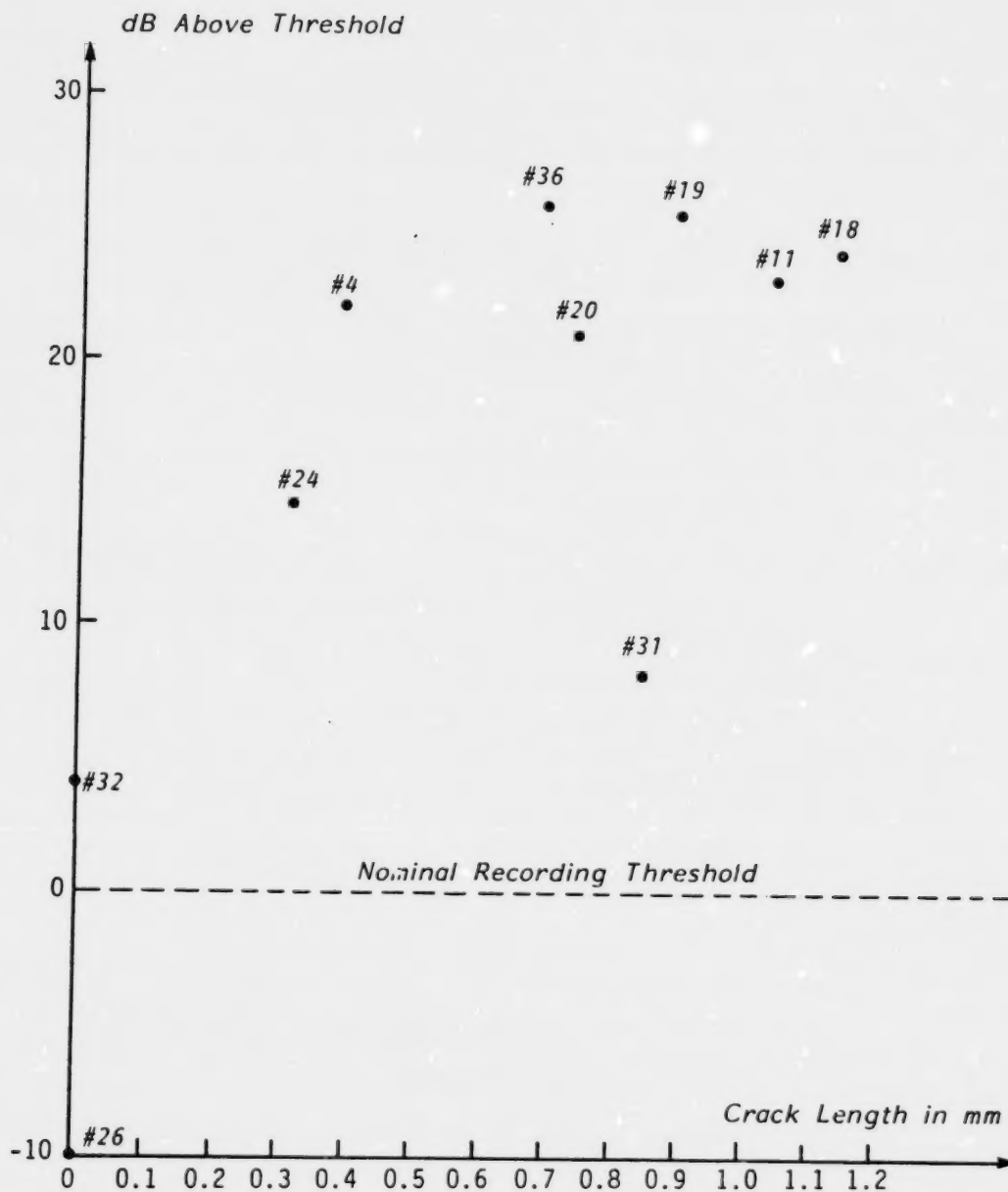
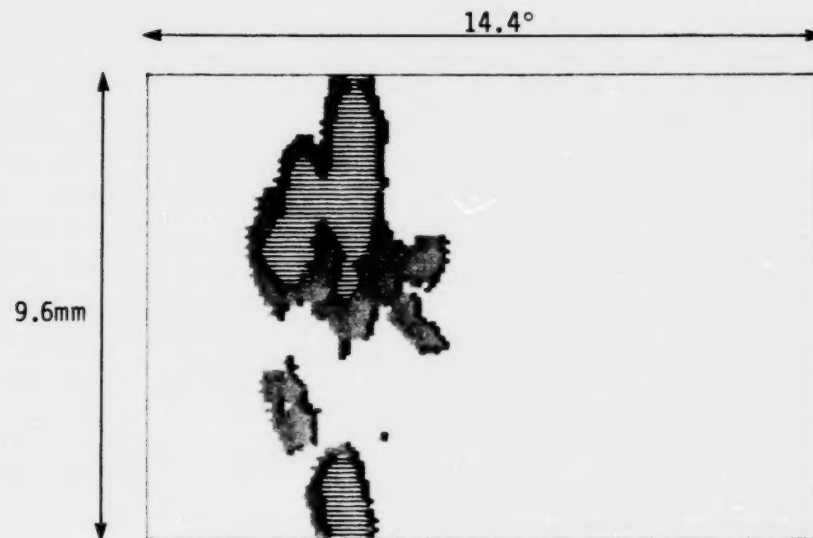


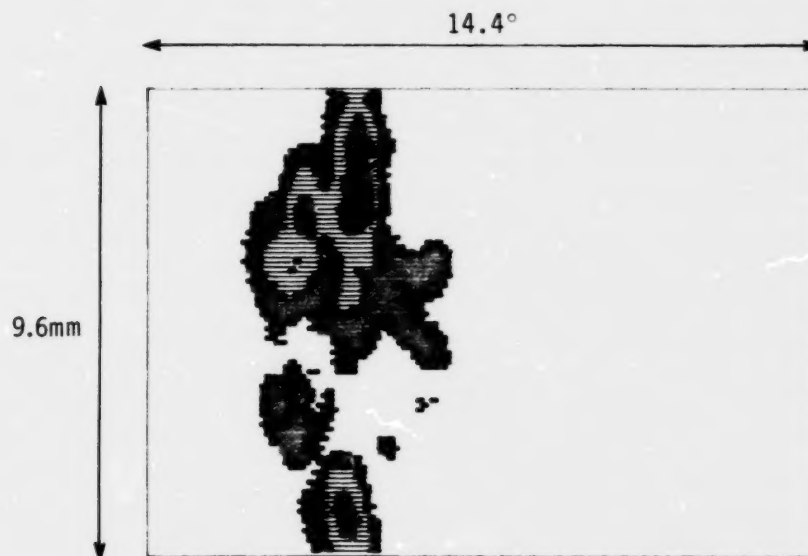
FIGURE 31
PLOT OF AVERAGE SIGNAL
AMPLITUDE VS CRACK LENGTH MEASURED FROM REPLICAS



K05
C-Scan

Centre Blister Using CCW Probe at 35 dB.
No Distortion C-Scan ($14.4^\circ \times 0.1$ mm Steps)
with 20% and 40% FSH Thresholds.

FIGURE 32



K05
C-Scan

Centre Blister Using CCW Probe at 35 dB.
No Distortion C-Scan (14.4° by 0.1 mm
Steps) with 18%, 20%, 38%, 40%, 78% and
80% FSH Thresholds. The 18-20, 38-40,
78-80 levels are set in black for clarity.
(Multilevel scan)

FIGURE 33

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